Milankovitch ice sheet and paleo-sea level models have been confronting the same sedimentary problem –

& the parallels don't stop there

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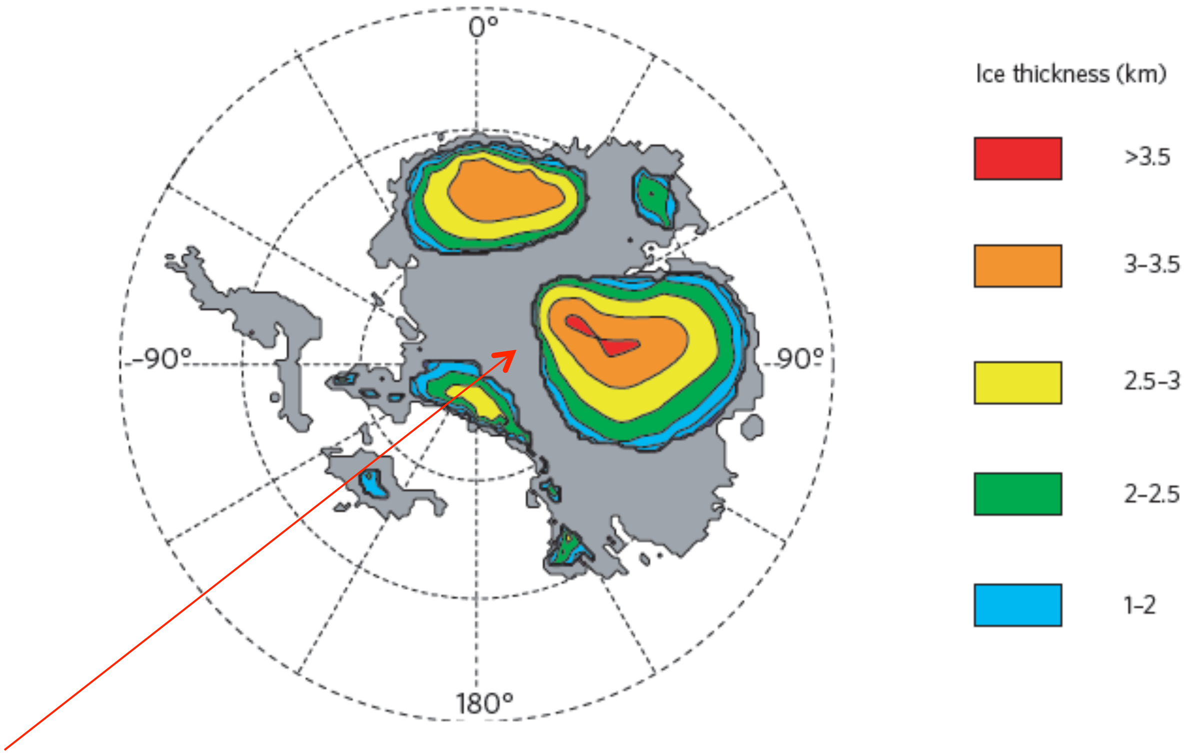
PALAEOCEANOGRAPHY

Broken greenhouse windows

Large and rapid global sea-level changes indicate that polar ice sheets may have ephemerally existed during the Cretaceous greenhouse climate. Two oxygen isotopic studies provide evidence for and against this conclusion.

Kenneth G. Miller

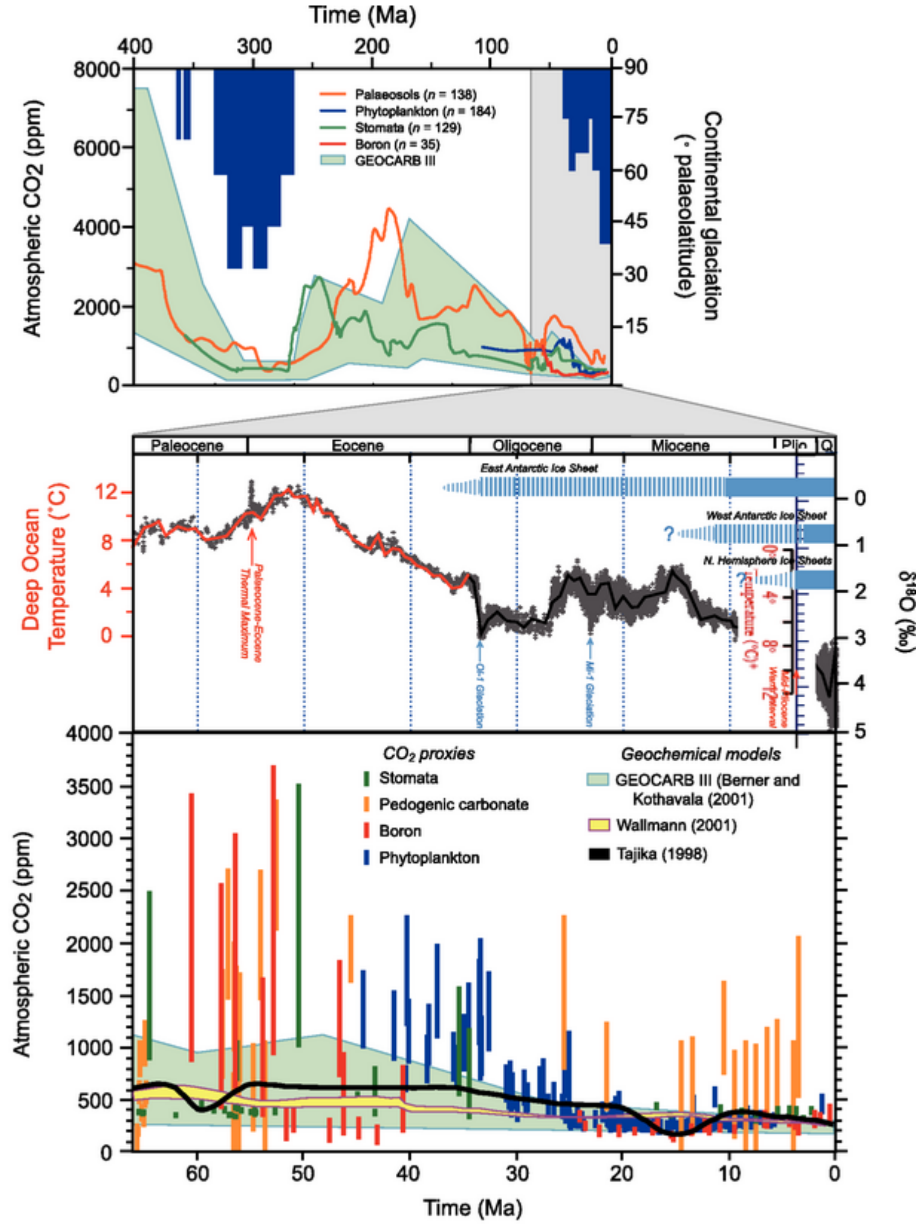


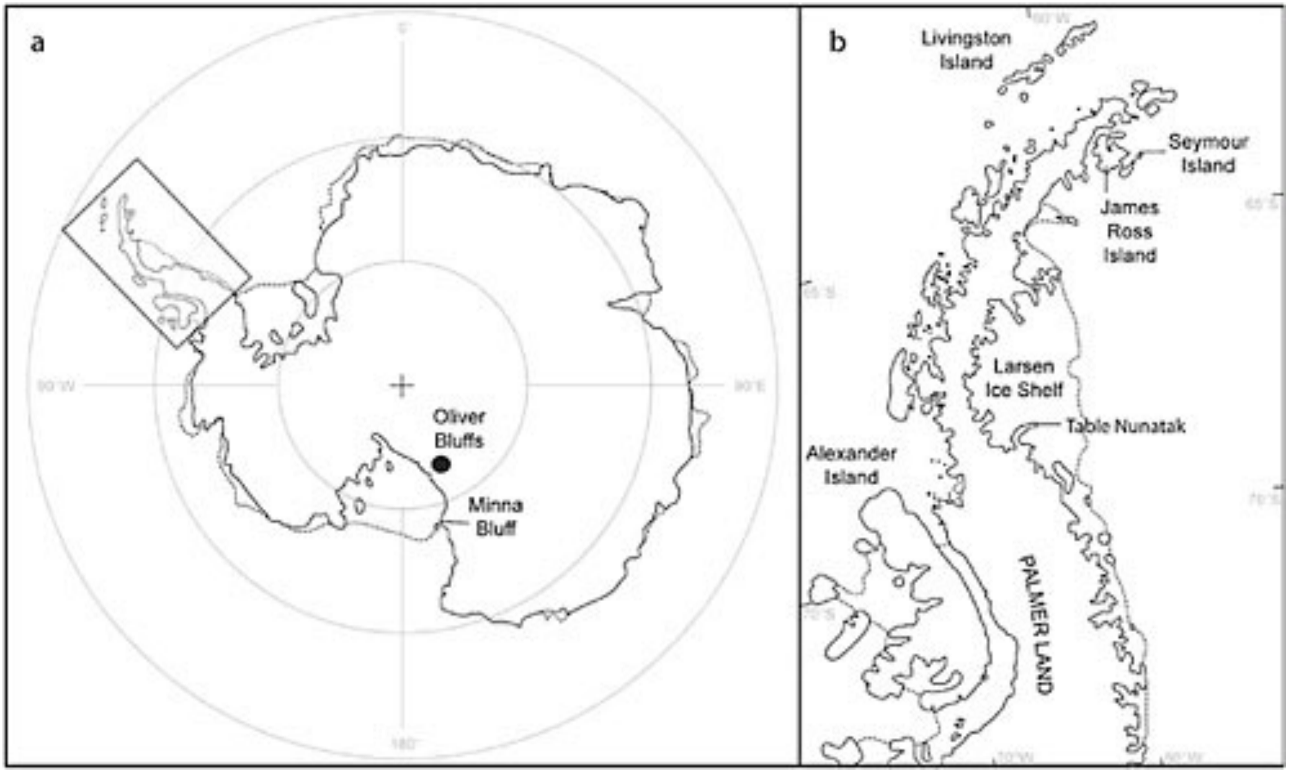
Proposed 25-m water equivalent Cretaceous Ice Sheets

Present Volume ~ 57 meters (Lythe et al, JGR, v106(B6), 2001, p. 11335

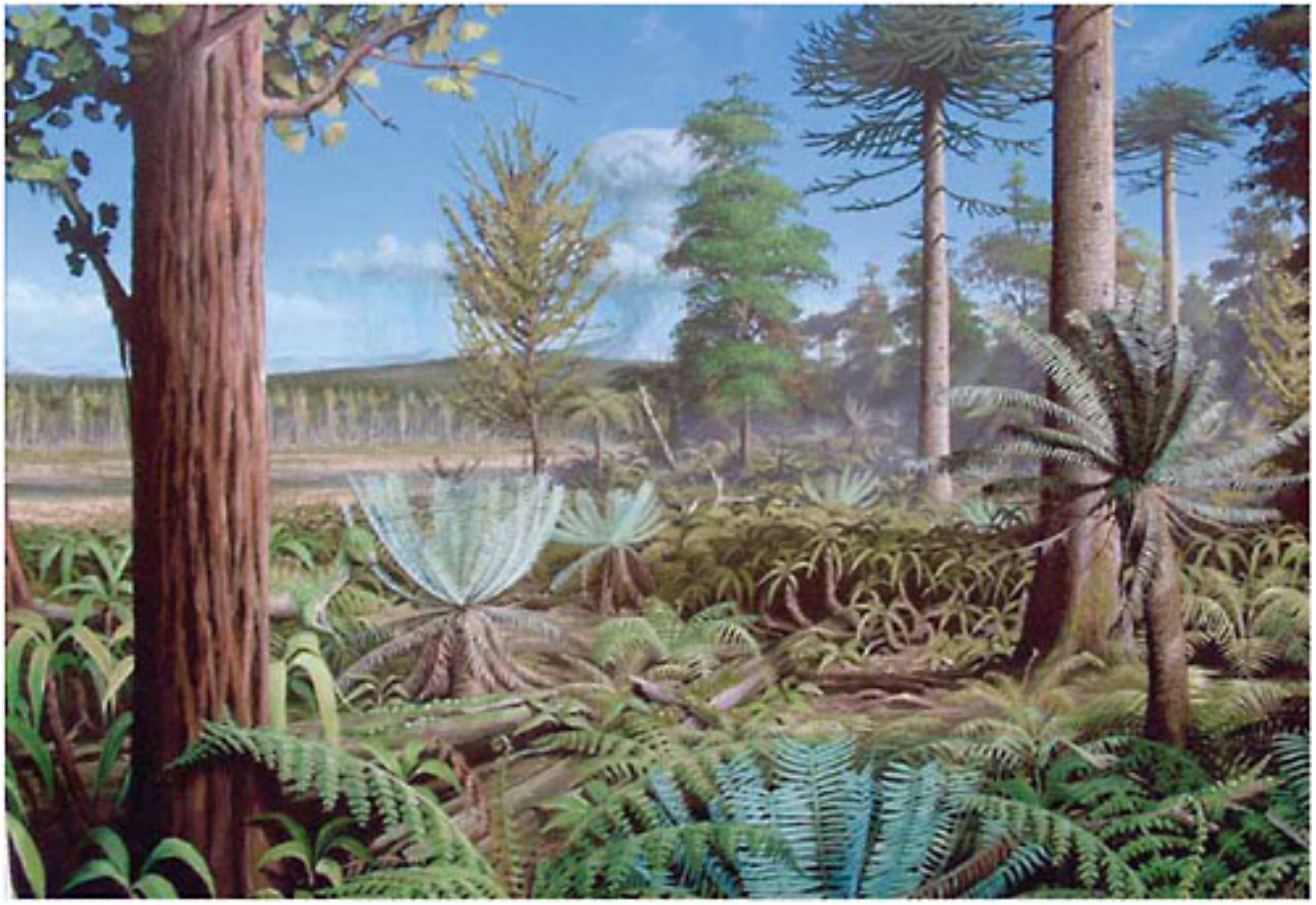
Phanerozoic CO2

Cenozoic CO2




a
Oliver
Bluffs
Minna
Bluff
b
Livingston
Island
Seymour
Island
James
Ross
Island
Larsen
Ice Shelf
Table Nunatak
Alexander
Island
PALMER LAND

Alexander Island Plant Reconstruction Coniacian Santonian ~87 Mya



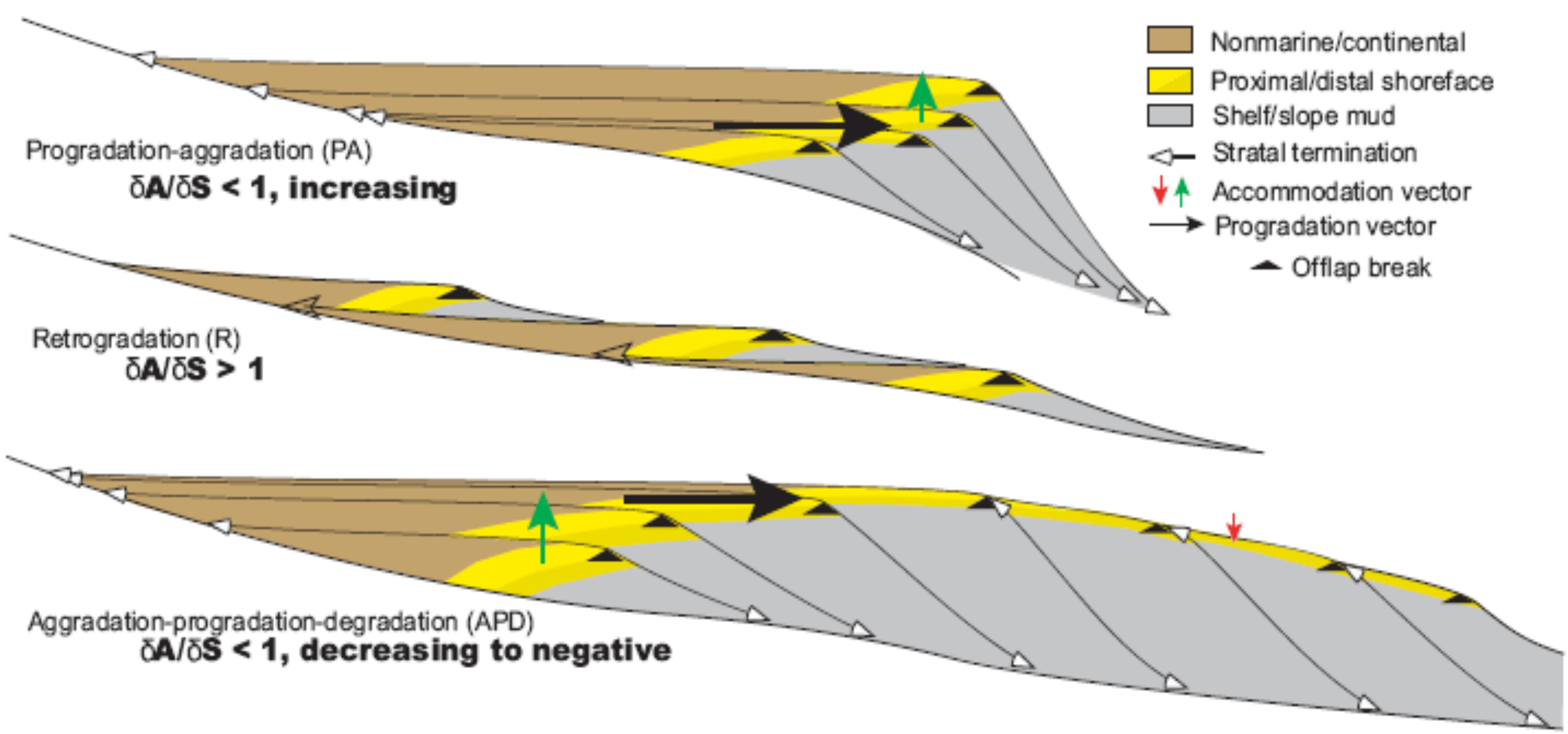
Howe (2003)

"….the climate was generally warm and humid to allow the growth of large conifers, with mosses and ferns in the undergrowth."

Mean Annual Temperature: 17-19 ^{o}C
70^{o} South Latitude

Sequence stratigraphy hierarchy and the accommodation succession method

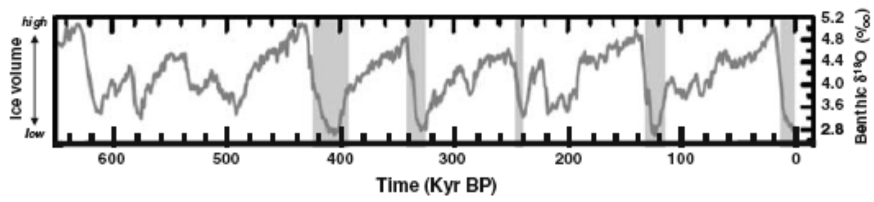
Jack Neal and Vitor Abreu
ExxonMobil Exploration Company, 233 Benmar Drive, Houston, Texas 77060, USA

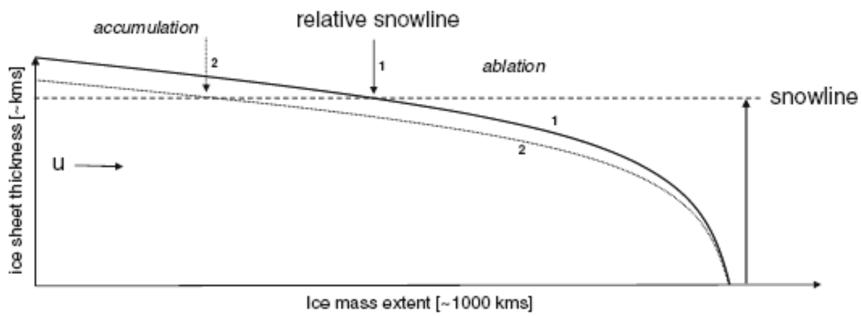


Alternative Framework

- Insufficient or non-existent Cretaceous/Antarctic glaciation to explain coastal transgressive-regressive cycles.
- No equivalent eustatic mechanism with similar rates, amplitudes or frequency exists.
- Eustatic sea level did not rise and fall so rapidly.
- **Sedimentary systems themselves are cycling with very weak or perhaps even no eustatic forcing.**
- **A complete set of parallels exist between this and the Milankovitch 100 Kyr Late Pleistocene ice sheet cycle – i.e. the "100 Kyr problem."**

Late Pleistocene 100 Kyr Ice Volume Cycles



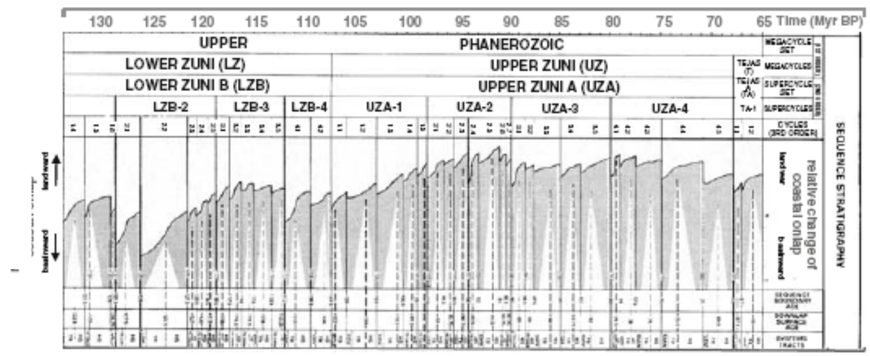


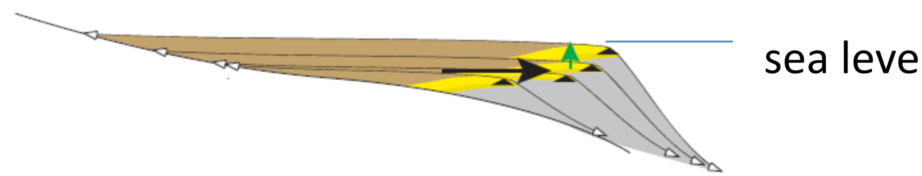
Mass transport is nonlinear diffusion

Milankovitch theory showed that snowline forcing was insufficient *by itself* to cause cycle

Ice sheet models have indicated that such 'passive' sedimentary systems can auto-oscillate.

Cretaceous 1-2 Myr Relative Sea Level Cycles





Mass transport is nonlinear diffusion

Cretaceous climate theory showing that sea level forcing was insufficient *by itself* to cause cycle

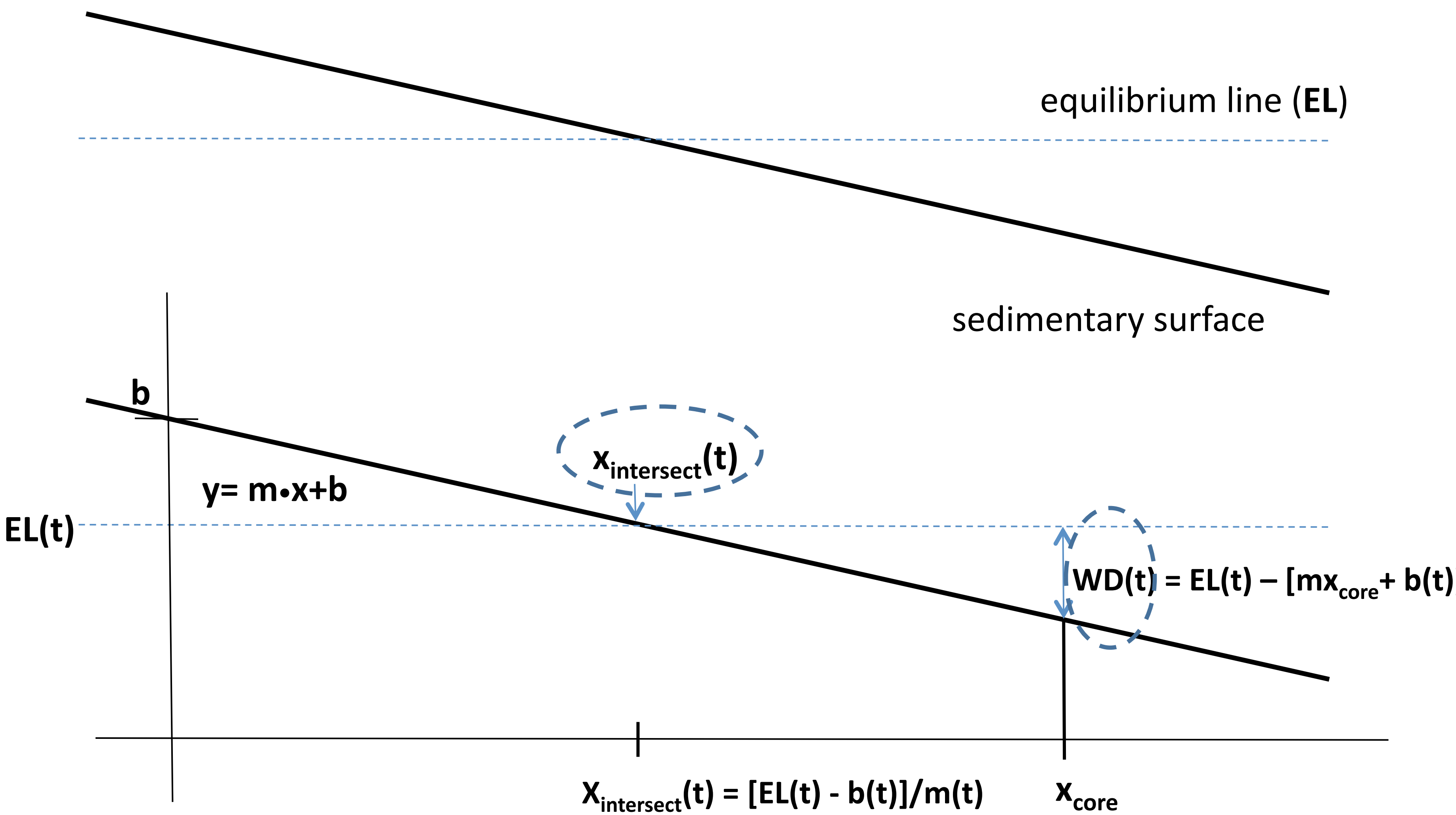
In the absence of eustatic sea level changes, why couldn't passive sedimentary basin systems auto-oscillate ?

What constitutes a “sedimentary system” ?

Joseph Barrell, “Rhythms and the Measurements of Geologic Time,” 1917, p. 778 – 782.

“… the sediments whose interpretation form the basis of earth history have been characteristically deposited with respect to a nearly horizontal controlling surface. This surface of control is baselevel … sedimentation as well as erosion is controlled by baselevel and …[it is] the surface at which neither erosion nor sedimentation takes place … baselevel may be used as a wide and inclusive term, applying both to land and sea …”

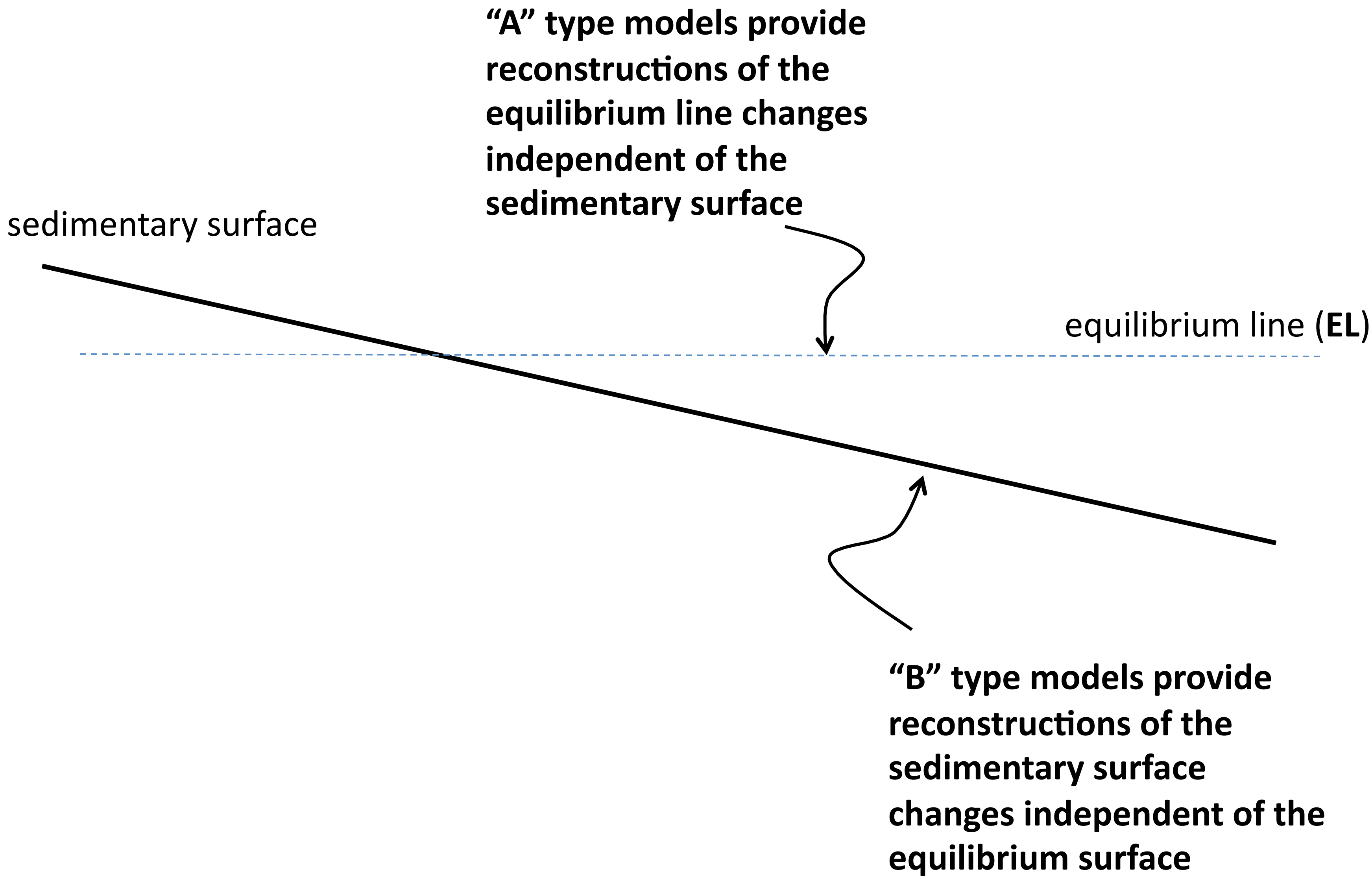
BASIC PROBLEM: Changes in all relative dimensions can be due to an *infinite combination of rates* for the two surfaces



One cannot solve one equation for two unknowns …

$$A + B = 5$$

A second ***independent*** equation involving A or B or both is needed.


“A” type models provide reconstructions of the equilibrium line changes independent of the sedimentary surface
sedimentary surface
equilibrium line (EL)
“B” type models provide reconstructions of the sedimentary surface changes independent of the equilibrium surface

CRETACEOUS “GREENHOUSE”

Ocean basin volume & water volume models

Palaeo-eustatic sea-level models “backstripping” models

Cretaceous “greenhouse” record for relative sea level changes

$$A + B = C$$

Milankovitch theory & ice sheet models

Direct reconstructions of ice sheet elevation changes thru time from field data.

Late Pleistocene $\delta^{18}O$ record for ice volume

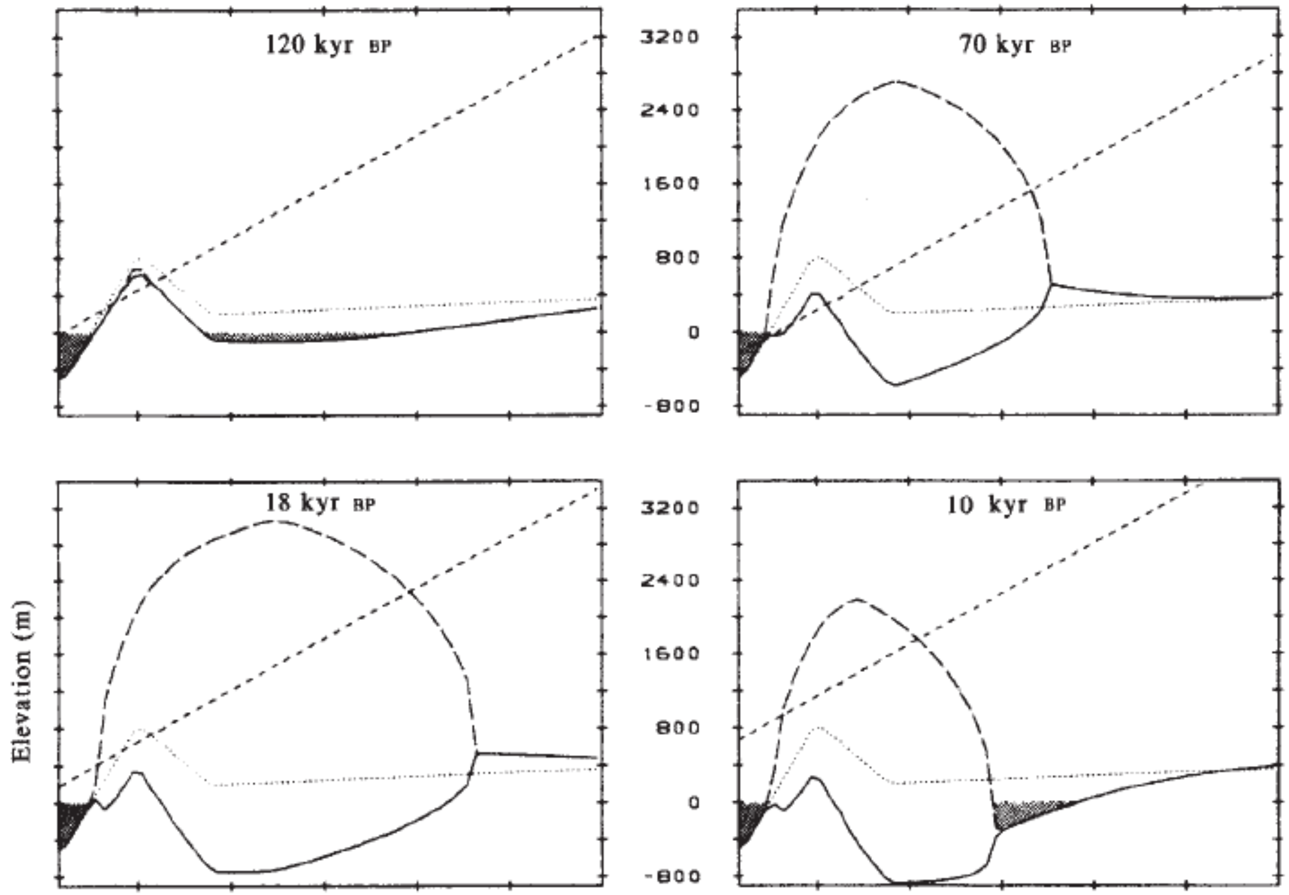
PLEISTOCENE “ICE HOUSE”

M. Milankovitch, "Canon of Insolation and The Ice Age Problem," 1941, Preface, p. XV

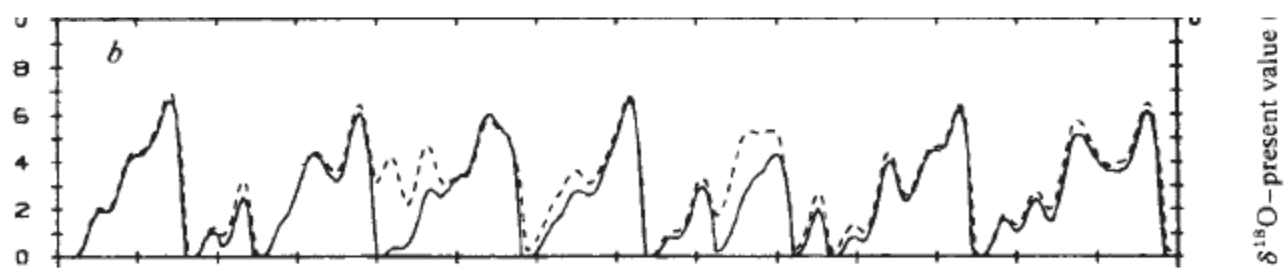
"…The most important result concerned the question of whether the influence of the variability of the astronomical elements … on the march of insolation was sufficient to fully explain the largest climatic fluctuations of the Quaternary… ***I began by analyzing mathematically the connection between the altitude of the snowline and the radiant energy corresponding to the caloric summer half-year. I found that a shift of the snowline by one meter corresponded to a change of this energy by one canonic unit. With this result the most important climatic effect of the pre-historic course of terrestrial radiation, i.e., the displacement of the snowline caused by it could be determined…*****"**

Manifestly a Type-A Model !

e.g. Pollard, 1982



Simulated Ice volume $\delta^{18}O$



Is this an A-type of B-type model ? – DEFINITELY "A"

What is a B-type model for the Milankovitch problem ?

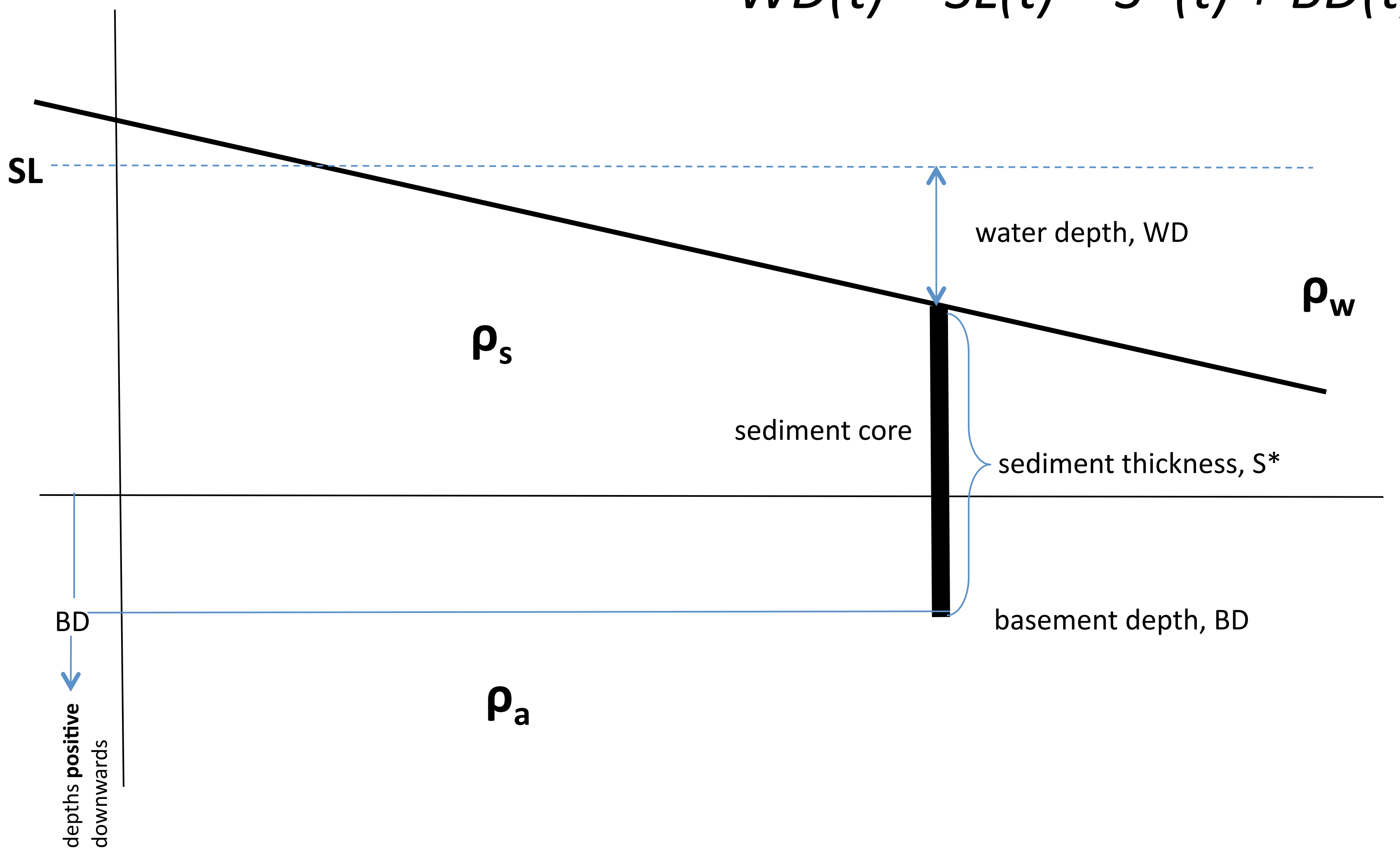
- **Direct reconstructions of ice sheet surface elevation changes through time.**

- Many constraints on ice sheet geometry from field indicators, isostatic rebound, $\delta^{18}O$ etc but …

- Hard to summarize the extent to which a time-series for surface geometry has been developed …

Now I want to apply the same A-B framework to Cretaceous sea level problem

$$WD(t) = SL(t) - S^*(t) + BD(t)$$



$$WD(t) = SL(t) - S^*(t) + BD(t)$$

If you were to use this equation to estimate SL => you must first estimate, WD, S* and BD.

If you are estimating S* and BD, *then you are estimating sediment core-top (surface) elevations*.

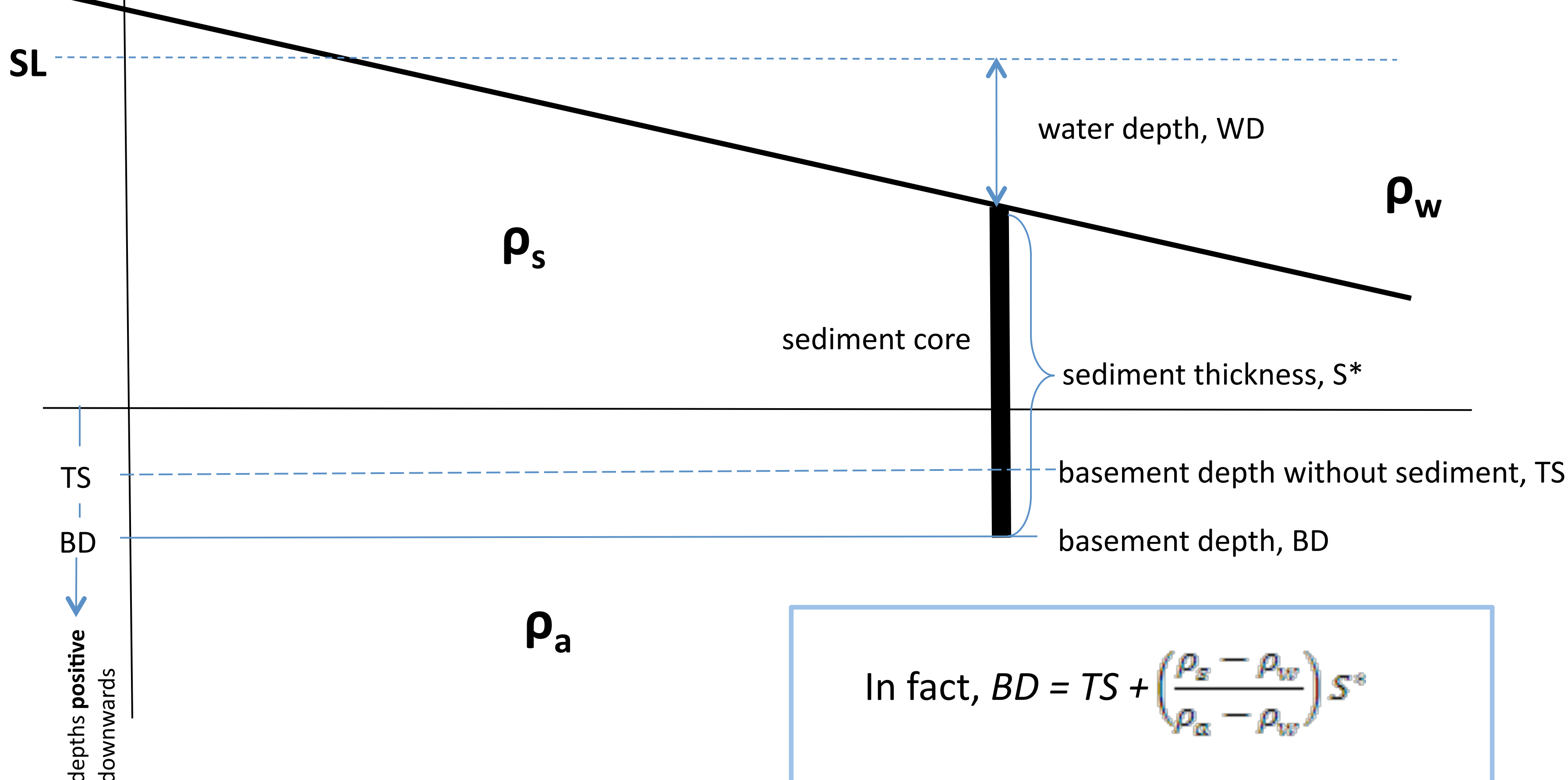
THIS IS A B-TYPE MODEL

The "Backstripping" Equation:

$$WD(t) = \Delta SL(t)\left[\frac{\rho_a}{\rho_a - \rho_w}\right] - S^*(t)\left[\frac{\rho_a - \rho_s}{\rho_a - \rho_w}\right] + TS(t)$$

$$\updownarrow ?$$

$$WD(t) = SL(t) - S^*(t) + BD(t)$$



In fact, $BD = TS + \left(\frac{\rho_s - \rho_w}{\rho_a - \rho_w}\right) S^*$

So …

$$WD(t) = \Delta SL(t)\left[\frac{\rho_a}{\rho_a - \rho_w}\right] - S^*(t)\left[\frac{\rho_a - \rho_s}{\rho_a - \rho_w}\right] + TS(t)$$

$$\Longleftrightarrow \quad WD(t) = SL(t) - S^*(t) + BD(t)$$

Backstripping data can equivalently be used to construct WD, S* and BD to get sea level

Since S* and BD give the sedimentary surface elevation

This is a B-type model and approach to the relative WD attribution problem.

What are A-type sea level models ?

- Direct reconstructions of ocean basin volume changes

- Direct reconstructions of water volume changes – eg $\delta^{18}O$

- **The *absence* of ice sheets is an "A"-type reconstruction too !**

FORUM Environmental dynamics

Simplicity versus complexity

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In modelling, simplicity isn't simple

CHRIS PAOLA

LANDSAT 7/USGS/NASA

Sequence stratigraphy hierarchy and the accommodation succession method

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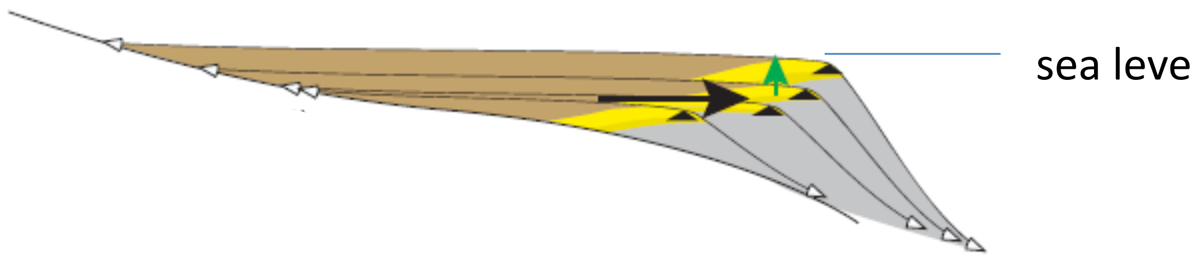
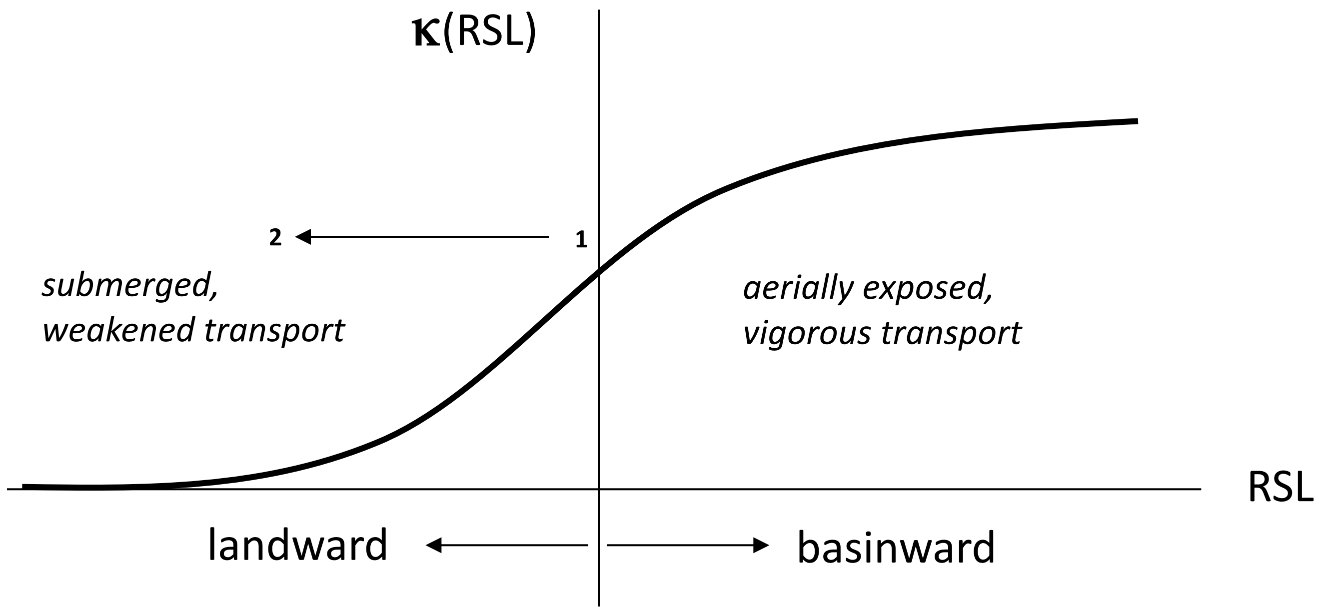
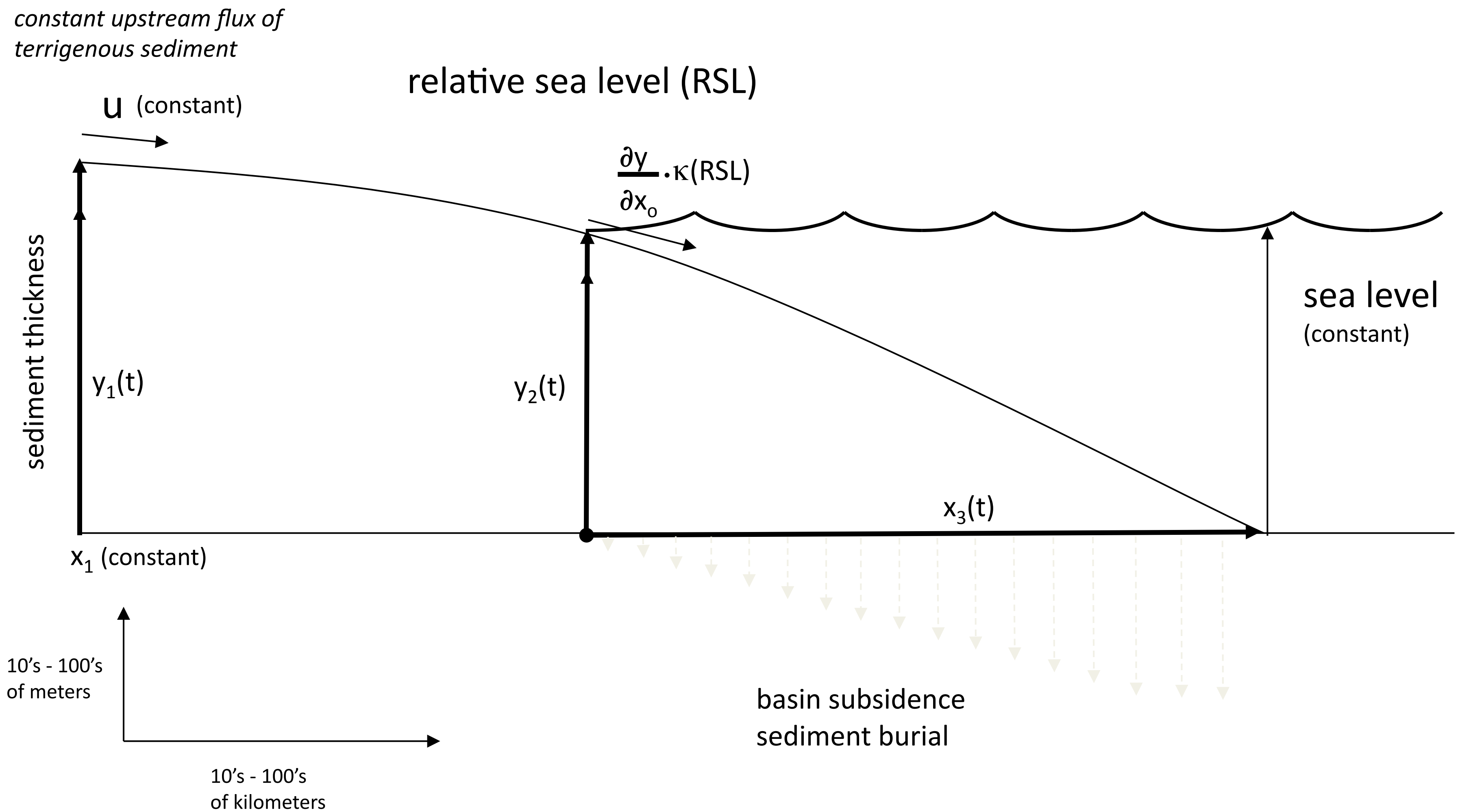
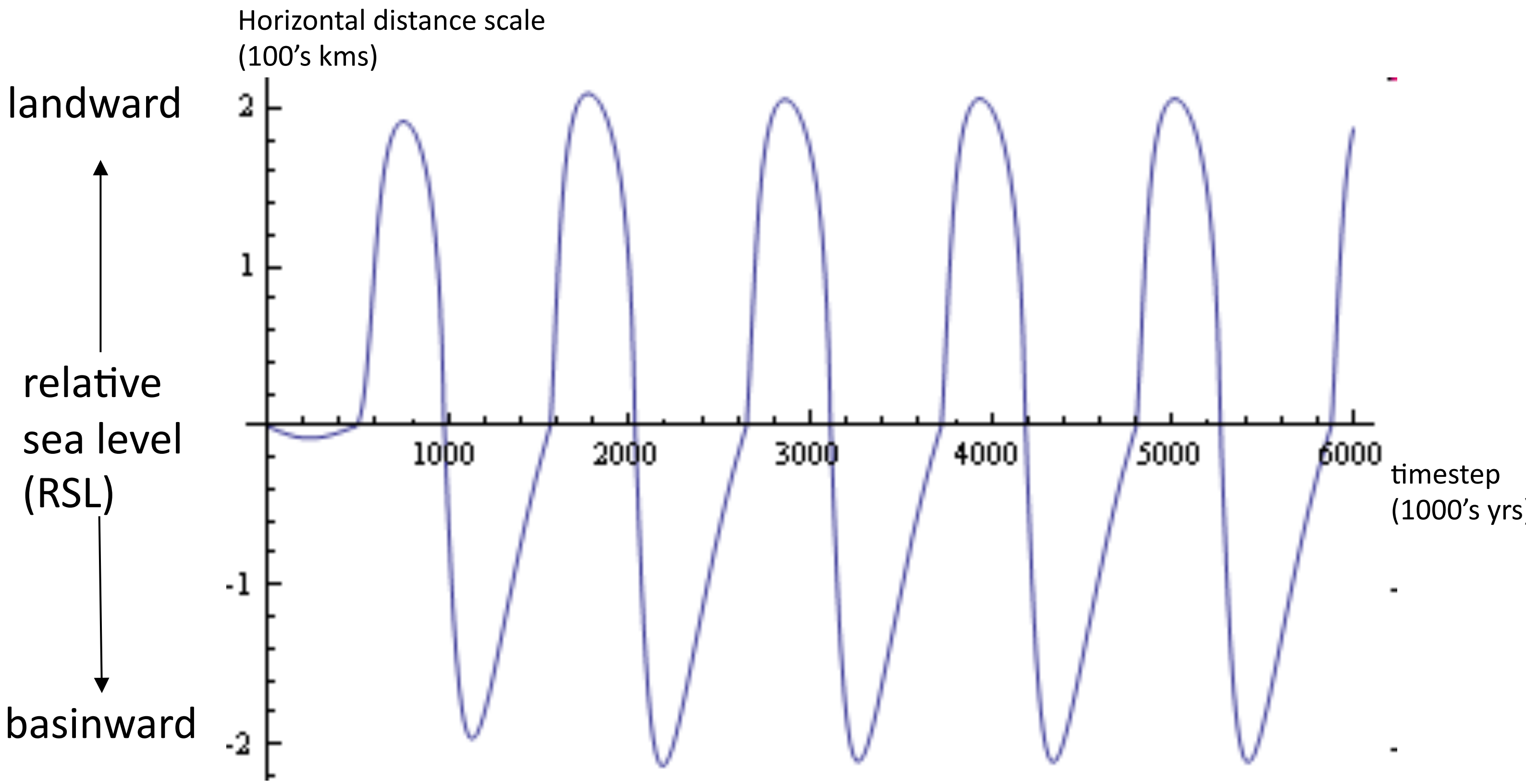
ExxonMobil Exploration Company, 233 Benmar Drive, Houston, Texas 77060, USA




κ(RSL)
2
1
submerged,
weakened transport
aerially exposed,
vigorous transport
RSL
landward
basinward



constant upstream flux of terrigenous sediment
relative sea level (RSL)
u (constant)
$\frac{\partial y}{\partial x_o} \cdot \kappa(RSL)$
sediment thickness
$y_1(t)$
$y_2(t)$
sea level
(constant)
$x_3(t)$
x_1 (constant)
10's - 100's of meters
10's - 100's of kilometers
basin subsidence
sediment burial



Horizontal distance scale
(100's kms)
landward
relative
sea level
(RSL)
basinward
2
1
-1
-2
1000
2000
3000
4000
5000
6000
timestep
(1000's yrs)

CONCLUSIONS:

Milankovitch ice sheet and paleo-sea level models have been confronting the same sedimentary problem –

& the parallels don’t stop there